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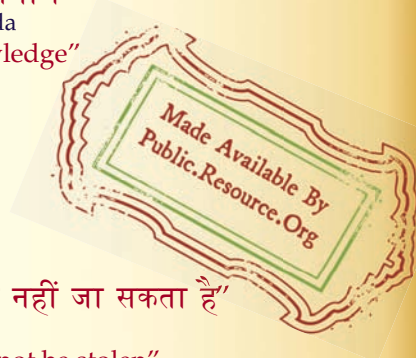
IS 14989 (2001): Recommended Practices for Seismic Qualification of Electrical Equipment of the Safety System for Nuclear Generating Stations [LITD 8: Electronic Measuring Instruments, Systems and Accessories]



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Bhartrhari—Nitiśatakam

“Knowledge is such a treasure which cannot be stolen”

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भारतीय मानक

नाभिकीय उत्पादन केंद्रों के लिए सुरक्षा तंत्र के विद्युत
उपस्करणों की भूकंपी योग्यता के लिए अनुशंसित रीतियाँ

Indian Standard

**RECOMMENDED PRACTICES FOR SEISMIC
QUALIFICATION OF ELECTRICAL EQUIPMENT
OF THE SAFETY SYSTEM FOR NUCLEAR
GENERATING STATIONS**

ICS 27.120.10; 27.120.20

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NATIONAL FOREWORD

This Indian Standard which is identical with IEC 60980 (1989) 'Recommended practices for seismic qualification of electrical equipment of the safety system for nuclear generating stations' issued by the International Electrotechnical Commission (IEC), was adopted by the Bureau of Indian Standards on the recommendation of Nuclear Instrumentation Sectional Committee (LTD 26) and approval of the Electronics and Telecommunication Division Council.

The text of the IEC standard has been approved as suitable for publication as Indian Standard without deviations. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

- a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'.
- b) Comma (,) has been used as a decimal marker while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

Only the English language text in the International Standard has been retained while adopting it in this standard.

CROSS REFERENCES

The technical committee responsible for the preparation of this standard has reviewed the provisions of the following International Standard and has decided that it is acceptable for use in conjunction with this standard :

IEC 60780 (1998) Nuclear power plants — Electrical equipment of the safety system — Qualification.

Indian Standard
**RECOMMENDED PRACTICES FOR SEISMIC QUALIFICATION
OF ELECTRICAL EQUIPMENT OF THE SAFETY SYSTEM
FOR NUCLEAR GENERATING STATIONS**

1 Scope and object

This standard is applicable to electrical equipment and the instrumentation and control equipment (I & C) of the safety system that is used in nuclear power generating stations including components or equipment of any interface whose failure could adversely affect the performance of the safety system.

This standard presents acceptable seismic qualification methods and requirements to demonstrate that electrical and I & C equipment can perform their safety-related functions during and after an earthquake. As seismic qualification is only a part of equipment qualification, this standard shall be used in conjunction with IEC 780.

2 Definitions

In addition to definitions contained in IEC 780, the following definitions establish the meanings of words in the context of their use in this standard.

In general, this standard is based on IAEA terminology.

2.1 *Device*

An item of electrical equipment that is used in connection with, or as an auxiliary to, other items of electrical equipment.

2.2 *Assembly*

Two or more devices including a common mounting or supporting structure.

2.3 *Active equipment*

Item for which the safety-related function is required to be performed by means of a mechanical motion or change of state.

2.4 *Passive equipment*

Item whose safety-related function is the maintenance of structural integrity and for which a change of state is not required.

2.5 *Malfunction*

The loss of capability of the equipment to initiate or sustain a required function, or the initiation of undesired spurious action which might result in adverse consequences. Functional acceptance criteria shall be specified by relevant specifications.

2.6 *Natural frequency*

A natural frequency of a structure or body is the frequency of its free vibrations depending only on its own physical characteristics (mass, shape, elasticity and damping distribution) and restraints and supports (see figure 1).

2.7 *Sine beat*

A continuous sinusoidal wave of one frequency whose amplitude is modulated by a sinusoidal wave of a lower frequency as shown in figure 2.

2.8 *Sine dwell*

A continuous sinusoidal wave at a single frequency.

2.9 *Test frequency*

The frequency of the applied force by which the specimen is excited during the test.

2.10 *Response spectrum*

Plot of the maximum response, as a function of oscillator frequency, of an array of single-degree-of-freedom damped oscillators subjected to the same base excitation (see figure 4).

2.11 *Narrow-band response spectrum*

A response spectrum that describes motion in which amplified response occurs over a limited (narrow) range of frequencies.

2.12 *Broad-band response spectrum*

Response spectrum that describes motion in which amplified response occurs over a wide (broad) range of frequencies

2.13 *Required response spectrum (RRS)*

Response spectrum issued by the user as part of the specifications for proof testing, or artificially created to cover future application. The RRS constitutes a requirement to be met (see figures 1 and 2).

2.14 *Test response spectrum (TRS)*

Response spectrum that is obtained from the actual motion of the shake table by analytical techniques or by spectrum analysis equipment.

NOTE - In equipment qualification, the TRS shall be compared to the RRS (see figure 1).

2.15 *Power spectral density (PSD)*

Mean squared amplitude per unit frequency of a waveform. PSD is expressed in g^2/Hz versus frequency for acceleration waveforms.

2.16 *Preferred testing axes*

Three orthogonal axes which correspond essentially to the most vulnerable axes of the specimen.

2.17 *S1 earthquake**

Earthquake which could affect the location during the operating life of the equipment to be qualified. For this type of earthquake, components shall be designed to continue to operate without modification.

2.18 *S2 earthquake**

Earthquake which produces the maximum vibratory ground motion for which certain structures, systems and components are designed to remain functional. Those are essential to assure proper function, integrity and safety of the total system which is to be qualified.

2.19 *Floor acceleration*

Acceleration of a particular building floor or level resulting from a specific earthquake's motion.

2.20 *Zero period acceleration (ZPA)*

Acceleration level of the high frequency, non-amplified portion of the response spectrum. This acceleration corresponds to the maximum peak acceleration of the time history from which the spectrum is derived.

2.21 *Significant cycle*

Cycle for which the amplitude range is between 50 % to 100 % of the maximum amplitude of the motion.

2.22 *Qualification testing*

Seismic qualification testing means subjecting the equipment to a suitable vibratory input motion so as to ensure that the equipment is capable of withstanding vibratory loads equal to or greater than those produced by seismic event(s). The seismic events are normally represented by the required response spectrum.

2.23 *Fragility*

Susceptibility of equipment to malfunction as a result of structural or operational limitation, or both.

2.24 *Fragility level*

Highest level of input excitation, expressed as a function of input frequency, that equipment can withstand and still perform the required safety related function. The fragility level can be expressed in terms of response spectrum (fragility response spectrum FRS) that is a TRS obtained from tests to determine the fragility level.

* The definitions of S1 and S2 earthquakes given by IAEA Safety Guide 50-SG-S1 are:

- Ground motion level 1 (S1):

Maximum ground motion which reasonably can be expected to be experienced at the site area once during the operating life of the nuclear power plant.

- Ground motion level 2 (S2):

Ground motion which is considered to be the maximum earthquake potential at the site area.

3 Earthquake environment and equipment response

This clause is intended to provide information on earthquake behavior and on the dynamic performance of equipment during earthquakes and simulated seismic events. Numerical values are typical and illustrative but should not be considered as standards.

3.1 *Earthquake environment*

Earthquakes produce random ground motions which are characterized by simultaneous but statistically independent horizontal and vertical components. An earthquake of magnitude 6 or higher on the Richter scale may persist for 15 s to 30 s and produce a maximum horizontal ground acceleration from 0,1 g to 0,6 g or higher with the major energy content usually occurring in the first 5 or 10 s. The typical broad-band random motion occurs over a frequency range from 1 Hz to 35 Hz.

3.2 *Equipment on foundations*

Amplitude of the ground motion (both horizontal and vertical) can be magnified in foundation-mounted equipment. For any given ground motion, the magnification depends on the system's natural frequencies of vibration (soil, foundation and equipment) and the mechanisms of damping (see 3.6). The typical broad-band response spectra that describes the ground motion indicates that multiple frequency excitation predominates.

3.3 *Equipment in structures*

The ground motion (horizontal and vertical) may be filtered and amplified by intervening structures to produce different motions. The dynamic response of floor-mounted equipment may reach an acceleration many times that of the maximum ground acceleration, depending upon the system damping and natural frequencies of vibration. The magnification and bandwidth depend upon the dynamic response characteristics of each building and equipment structure.

3.4 *Simulating the earthquake*

The goal of simulation is to reproduce the effects of the postulated earthquake motion as closely as possible.

The form of the simulated seismic motion used for the qualification of equipment, by analysis or testing, can be described by one of the following: time history, response spectrum, or the power spectral density (PSD) function. These data may be generated for the structures upon which the equipment is to be mounted. They are supplied by the user or his agent to the manufacturer as a part of the specifications for that equipment (see clause 5) or provided by the manufacturer to cover future applications.

Because of the directional nature of seismic motion as well as the filtered output motion of structures, the directional components of the motion and their application to the equipment should be specified.

3.5 *Time history*

The expected form of the motion is obtained from existing earthquake records or may be artificially generated. For application at any floor, the time history record generated includes the dynamic filtering and amplification effects of the building and other intervening support structures (see figure 5).

3.6 *Damping*

Damping is the generic name ascribed to the numerous complex energy dissipation mechanisms in a system. In practice, damping depends on many parameters, such as the structural system, mode of vibration, strain, force in normal situations, speed of application of this force, materials, joint slippage, etc.

In linear vibration theory, the simplifying assumption is made that damping is purely viscous, or dependent on the relative velocity of moving parts. Therefore, when a value of damping is associated with a practical system, it is usually assumed to be equivalent viscous or linear damping which is a convenient simplified way of relating real-world hardware behavior, which may be non-linear to some degree, with theoretical concepts which normally utilize linear methods of analysis.

4 **Seismic qualification requirements**

4.1 *Introduction*

The seismic qualification shall demonstrate the safety system equipment's ability to perform its required function during and/or after the time it is subjected to the forces resulting from one S2 earthquake. In addition, the equipment should withstand the effects of a number of S1 earthquakes prior to the application of an S2 earthquake (see clause 6).

Qualification of electrical items of the safety system for nuclear power generating stations is fully described in IEC 780 and, in particular, clause 4 of that standard describes the principles of qualification. Seismic testing shall be performed in the proper test sequence with the environmental testing where required (see annex A). This standard may be used by equipment manufacturers to establish procedures that will yield data to substantiate performance claims or by equipment users to evaluate and verify performance of representative devices and assemblies as part of an overall qualification effort.

In summary, qualification is a formal process by which the required demonstration is achieved in an unambiguous recorded and traceable manner so that its applicability and validity can readily be confirmed.

4.2 *The process of seismic qualification*

Due to its formal nature, seismic qualification will include a number of recognizable steps (see clause 5). These are :

4.2.1 *Specification of the equipment to be qualified*

The equipment shall be clearly specified.

The specification shall include:

- a description of the equipment, its type number, drawing and issue number, specification, etc.;
- the boundaries of the equipment to be qualified, for example: which input/output connections are involved, which mountings are to be included or excluded, etc.;
- the operating conditions (loadings) which are necessary;
- ageing conditions according to 5.3.3 and 5.3.5 of IEC 780, see also 5.3.3 of this standard.

4.2.2 *Specification of the seismic requirements*

These requirements shall be clearly specified. They shall include at least:

- time duration;
- frequency range;
- acceleration values.

Information which provides these data may be:

- vibratory motion in terms of power spectral density as a function of frequency;
- the strong motion time duration of the earthquake;
- the required response spectrum (RRS) for the fixing points on which the equipment will be mounted. The RRS shall include data for the principal horizontal axis and the vertical axis, and should be specified for 2 %, 5 % and 7% damping ratio;
- maximum accelerations versus significant frequencies, or time history of the fixing point on which (floor or structure) the equipment will be mounted;
- details of the multiple S2 requirements (see 6.2.9.2).

In evaluating the seismic risk of a particular site, it may be necessary to make an allowance for the estimated number of S1 and S2 earthquakes to which the specimen might be subjected during the installation's lifetime. Five S1 and one S2 earthquakes are generally assumed unless a different number can be justified. However instead of five S1 a specimen may be subjected to two tests corresponding to level S2.

S1 seismic tests shall be followed by at least one S2 seismic test and the duration of each test wave shall be at least equal to the strong part of the time history used to define the RRS. If no time history is given, 10 significant cycles for the seismic tests should be used unless otherwise specified.

The test waves simulating S1 or S2 earthquakes may be applied as "wave train". In this case, the waves shall be sufficiently spaced by at least 2 s to avoid superimposing their effect on the equipment.

4.2.3 *Specification of acceptance criteria*

These are the factors on which the success or failure of qualification will be judged.

They shall be clearly specified and may indicate whether the equipment is to operate during the test or merely to survive and operate afterwards, and include:

- a listing or description of the safety functional requirements;
- a list of acceptance criteria in order to remain functional;
- identification of margins;
- any particular requirements for tests or analysis.

4.2.4 *The qualification tests or analysis*

The equipment defined in 4.2.1 shall be qualified to meet the requirements defined in 4.2.2. Success or failure shall be judged by means of the criteria specified in 4.2.3.

Some general methods to achieve this qualification are described in IEC 780:

- Qualification by analysis or combination of test and analysis in which the performance of the equipment is predicted without physical test or on the basis of existing data (see 5.3.2).
- Qualification by testing in which a typical example of the equipment is tested (see clause 6).
- Qualification by experience. Although not yet an established technique, recent data indicate that qualification by experience may be a valuable method of seismic qualification. This method is described in the annex A for guidance.

Each of the preceding methods, or other effective methods, may be adequate to verify the ability of the equipment to meet the seismic qualification requirements. Seismic qualification analysis (SQA) (tests, analysis or combination of both) establishes the particular procedures whose choice should be based on the practicality of the method for the type, size, shape and complexity of the equipment.

4.2.5 *Provision of documentation*

Clear and complete documentation shall be provided (see clause 7). This is an essential part of qualification. Its purpose is to demonstrate that the equipment meets performance requirements when subjected to the seismic accelerations for which it is to be qualified.

5 **Seismic qualification analysis (SQA)**

The seismic qualification analysis covers the methods to rationalize the operations (tests, analysis or combination of both) and ensures that sufficient margin accounts for the uncertainties.

The SQA assumes that the equipment will perform its intended functions if the sub-assembly and the correlative interfaces accomplish their respective functions under the conditions resulting from:

- the mutual coupling of the sub-assembly;
- the seismic loading induced by the seismic excitation required for the equipment;
- the loading related to the functional requirements of the equipment.

The effects of the above conditions on the sub-assembly shall be considered as acting simultaneously. Each sub-assembly may be considered separately.

SQA includes four successive steps, which are detailed hereafter:

- equipment review, sub-assembly selection;
- sub-assembly review, boundary conditions and interactions;
- qualification operation, tests or computations or a combination of both;
- synthesis, results and margin evaluation.

5.1 *Equipment review*

The purpose of this step is:

- to divide the actual equipment into several significant sub-assemblies (one or more, idealized or physically independent) (see figure 6);
- to determine the set of sub-assemblies which is representative of the actual equipment;
- to identify the sub-assembly which may be affected by modifications or alternate configurations.

The aim is to reconcile:

- the availability of test and computation facilities;
- the reliability of the results obtained in the qualification process;
- the optimal use of available data.

Sound engineering judgement is necessary; however, any erroneous choice would be revealed by the subsequent steps, so that the final conclusion cannot be affected.

5.2 *Sub-assembly review - Boundary conditions and interactions*

The purpose of this step is:

- to identify the function of each sub-assembly required for the adequate performance of the equipment; all the operating modes and postulated events shall be considered;
- to establish the loadings at interfaces for each sub-assembly and determine their significance.

5.2.1 *Coupling*

The behavior of sub-assemblies may be different, according to whether they are normally linked to the equipment or physically separated. Coupling effects induced by seismic events shall be examined.

5.2.2 *Seismic loading of sub-assemblies*

When the selected sub-assemblies are not directly mounted on the equipment support, they are subject to a seismic loading which shall be established on the basis of the following elements:

- the dynamic transfer properties of the sub-assembly supporting structure;
- the specified seismic loading of the equipment (usually defined by the RRS);
- a justifiable method of test, calculation or a combination of both.

Some of these methods are detailed in the following and shown in figure 7.

5.2.2.1 *Experimental method*

The specified seismic motion of the equipment support is simulated and the response in points of interest of the specimen is monitored (local response).

NOTE - Complementary analysis may be necessary to assess the representativeness of the specimen and test conditions or to amend the experimental data to account for coupling effects or alternative configurations of the equipment.

5.2.2.2 Calculation method

In a first stage, the modal parameters are identified by analyses depending on experiments or calculation.

Then, the local response of the equipment at points of interest may be determined, for example by:

- direct response spectra transfer;
- response of individual modes and superimposed effects.

NOTE - Tests may be necessary to verify the results of the complex mathematical models or to determine modal parameters for a better approximation to reality.

The seismic loading of the sub-assembly can be expressed in terms of RRS.

To account for analysis uncertainties and experimental errors, the peaks of the response spectra should be enlarged and broadened by a justified factor.

5.2.3 Loading

The loading is expressed by the physical conditions applied to the sub-assembly. In addition, the influence of the location and orientation of each sub-assembly shall be taken into account.

5.2.4 Properties of the sub-assemblies

- Linearity

The physical properties or the response of the sub-assemblies may be non-linear for example stiffness and therefore modal frequencies may change with stress level. In this case, the appropriate considerations will restrict the validity or mitigate the errors in experimental data or linear assumptions of models.

- Damping

Different damping values may be associated with the same constituent according to:

- stress levels (non-linearity effect);
- modes of vibration.

Unless other documented evidence is available, the following damping factor may be assumed:

- Control panel, cabinets: 7 % of critical damping (when welded 4 %)
- Motors: 2 % of critical damping (when welded 4 %)
- Cable trays: 10 % of critical damping (when welded 4 %)

If a device cannot be identified, a damping value of 5 % is suggested.

5.3 Qualification actions

The purpose of this step is to provide sufficient evidence and information on the behavior of the sub-assemblies, with the aim of demonstrating in the following step (synthesis) that the equipment may perform its safety functions under postulated seismic conditions.

The operations on the sub-assemblies shall be planned in order to investigate all the potential failure modes and malfunctions, which may be categorized as below:

- rigidity: the failure is related to the intensity of the seismically induced excitation (e.g. structural integrity);
- resonance: the failure is related to the intensity and frequency content of the seismically induced excitation (e.g. chatter of electrical contacts);
- cumulative damage: the failure is related to the intensity, the frequency content and the number of load cycles induced by seismic excitation.

Tests or computation may be used to investigate the behavior of the sub-assemblies.

Tests may be suitable for some sub-assemblies or particular simulations, and computation for some others. The following table illustrates the factors affecting this choice. An appropriate conservative margin shall be considered whenever the investigation method produces approximate results.

Method	Suitable field of investigation	Main accuracy factor	Usual margin
Tests	Complex functional input-output relationships	Test conditions (motion, type, environment simulation)	Severity of test loading
	Indeterminate failure modes	Specimen representativeness	
	Dynamic performance	Size, coupling effects, functional simulation	
Computations	Postulated failure modes (structural integrity)	Mathematical model accuracy	Safety conditions
	Extrapolation and interpolation of dynamic performance	Analysis method (static equivalent, modal analysis, modal spectral analysis, etc.)	

5.3.1 Tests

The procedures used to perform the tests are detailed in clause 6.

5.3.2 Computations

Computation may complement tests, to extrapolate or interpolate experimental data. Computation may also investigate established failure modes related to structural integrity, fatigue and stress-strain behavior.

Two methods of computation are suggested below:

- static equivalent load, which yields conservative results in return for the crude approximation of the model;
- dynamic analysis, which takes into account the modal properties of the structure and which can be suitably represented by linear models.

5.3.2.1 Static equivalent load calculation

The passive sub-assembly may be assumed to be subject to a constant and uniform equivalent acceleration as specified below:

- a) The fundamental frequency of the sub-assembly is established for each main orthogonal axis by calculation, modal testing or analysis.
- b) For each orthogonal axis, the applicable RRS (acceleration) is used to determine the maximum peak value within the interval of uncertainty of the fundamental frequency (see figure 8).

NOTES

- 1) The interval of uncertainty is estimated on an error calculation basis.
 - 2) If little or no frequency investigation has been performed, the uncertainty interval is wide and the maximum peak value (MPV) of the applicable RRS shall be selected.
 - 3) If evidence can be produced that the considered part is rigid, the ZPA value can be selected.
- c) For each axis, the equivalent acceleration values result from the above maximum values multiplied by 1,5, or less if justified, to account for the effects of the neglected modes.
 - d) For both directions of each main orthogonal axis, the relevant equivalent acceleration is applied to the masses of the considered sub-assembly to simulate the seismic loading.
 - e) The same seismic effects along each main orthogonal axis are superimposed, according to the square root of the sum of the squares.

5.3.2.2 Dynamic computations

The dynamic computations are based on three methods:

- a calculation method, usually implemented by a computer routine, to determine the modal parameters;
- a mathematical model of the considered structure and sub-assembly (often a finite element model or transfer matrix or other justifiable method);
- a calculation method to establish the effect of the modes under the action of applicable seismic loading (usually by spectral analysis).

NOTE - Modal testing may replace methods 1 and 2 and provide the modal parameters.

Justification shall be provided for the following points:

- Calculation methods

- . Basic principles of the method
- . Validation of the computer routines
- . Procedure for combining modal responses and directional responses.

- Model assumptions

- . Idealization principles
 - . Distribution of the model elements, number of dynamic degrees of freedom
 - . Values of parameters
 - . Non-linearity effects
 - . Damping.
- NOTE* - Tests may be advantageous to refine assumptions about damping, linearity, stiffness, etc.

- Results from the calculation method and the correlated model

- . Number of modes taken into account and total of equipment mass
 - . Effect of neglected rigid modes
 - . Accuracy.
- NOTE* - Tests may be necessary to validate these results.

5.3.3 Ageing

Age conditioning is required for those sub-assemblies having ageing mechanisms which may significantly affect the seismic behavior. In this case, a qualified life objective shall be determined, age conditioning shall be performed, prior to other simulation or investigation tests.

5.3.4 Interfaces

Contiguous elements may significantly interact with the considered sub-assembly. Attention will be paid to the support characteristics and the functional connections (such as cable trays, piping, etc.).

5.3.5 Specimen

When necessary, the simulations will be performed on specimens as representative as possible of the in-service conditions. However, alterations are acceptable in the following cases:

- The alteration of the specimen is not in conflict with the purpose of the simulation (for example dummy devices may simulate the mass distribution of a supporting structure to determine the mechanical transfer functions by vibration tests).
- The effects of the alteration can be predicted with reasonable precision.

5.3.6 Severity

Simulations and investigations on the sub-assembly shall consider the most severe combination of the loadings identified in step 2 of the SQA (seismic and functional loadings). To encompass the most expected modifications, or to take into account multiple applications, the sub-assembly should be qualified with a sufficient severity margin.

5.4 *Synthesis*

The purpose of this step is to verify the following points:

- The actual equipment is suitably represented by the set of sub-assemblies whose seismic behavior has been investigated and documented.
- For each representative sub-assembly, the loadings assumed in the investigations meet or exceed the actual in-service conditions and the seismically induced excitation of the equipment. Coupling effects between sub-assembly shall be included.
- The investigated performance of each sub-assembly conservatively enable the equipment to perform its safety function(s).

Synthesis is used to establish whether the qualification requirements are satisfied for equipment which shows some analogous properties with previously qualified equipment.

The following examples in figures 9 and 10 illustrate some suggested procedures.

6 **Seismic test qualification**

6.1 *Introduction*

The procedures indicated in this clause should be used for the seismic qualification testing of the safety system or other equipment designed to withstand earthquakes.

In general, a seismic test qualification program is recommended for complex assemblies (for which qualification by analysis is not possible) or for equipment in which possible malfunctions are related to functional performances. Therefore, the equipment should be tested under simulated operating conditions. The seismic test shall be performed by subjecting the specimens to a vibratory motion which conservatively simulates that to be seen at the equipment mounting location during the considered dynamic event.

A practical problem in attempting to define tests for qualifying specimens is in the selection of suitable testing waves, as detailed in 6.5. Numerous factors shall be taken into account including the type of specimen, its location and the nature of the earthquake expected, etc.

A further point of consideration is to determine whether the specimen is to be used for a unique application or for a more general purpose. In the first case, the seismic motion can be specified and the qualification testing selected to comply with the specification (proof tests), whereas in the latter case, the test shall be designed to qualify the specimen for future application, for which a more general seismic input motion would be specified (fragility tests). Another difficulty arises when attempting to define the testing of individual components (relays, motors, sensors, etc.) or complex assemblies such as control cabinets.

The theoretical basis for test procedures is considered to be outside the scope of this standard, but can be readily obtained from relevant technical literature.

6.2 *Test conditions*

The seismic qualification test program shall include the following elements:

- seismic loads and test sequence;
- input motion;
- mounting conditions;
- operational loads and operating conditions (for example voltage, pressure);
- monitoring of output response and functional performance of the equipment;
- demonstration of operability.

6.2.1 *Seismic loads*

Generally the seismic loads are defined by a required response spectrum (RRS). It is usually broadened in the maximum amplification area to cover the effects of unknown or variable factors such as the natural frequencies of the building structure which are not known with accuracy, or the specimen's position inside the building.

The requirements should state the extent to which the spectrum is broadened; if not, the RRS shall be considered broad-band. RRS does not give information about the duration of the corresponding time history and on the number of significant cycles.

These values should be specified. If not, the duration shall be not less than 30 s (except as noted) and the number of significant cycles shall range between 5 and 10.

6.2.2 *Input motion*

The input motion as described in 6.5, that shall be applied to the base of the specimen, shall be derived from the RRS in order to satisfy the criteria of 6.5 and 6.2.9.3.

6.2.3 *Mounting*

The equipment to be tested shall be mounted on the vibration table in a way that simulates the intended service mounting. The mounting method shall be the same as that recommended for actual service. The mounting method shall use the recommended bolt size and configuration, weld pattern and type, etc. The effect of electrical connections and sensing lines, etc., shall be considered. The orientation of the equipment during the test shall be documented and shall be the only orientation for which the equipment is qualified unless adequate justification can be made to extend the qualification to an untested orientation. The method of mounting the equipment to the shake table shall include a description of any interposing fixtures and connections. The effects of such fixtures and connections shall be evaluated if they are only used during qualification and not for in-service mounting.

6.2.4 *Loading*

Seismic qualification tests on equipment shall be performed with the equipment subjected to normal operating conditions. These shall include electrical loads, mechanical loads, thermal loads, pressure, etc., as far as they adversely affect the function.

The necessity and possibility of reproduction of full operating loads shall be evaluated for each equipment submitted to seismic test and the documentation shall demonstrate that the partial reproduction (or non-reproduction) of the loads will not invalidate the results of the tests.

6.2.5 *Monitoring*

Sufficient monitoring equipment shall be used to evaluate the functional performance of the equipment before, during (when required) and after the test. In addition, enough vibration monitoring equipment shall be used to allow determination of the applied vibration levels. In addition to monitoring the vibration table, it is recommended that as many points are monitored on the equipment itself as may be needed to provide information to evaluate the vibration behavior of the specimen. These data can also be used for future evaluation of the qualification of the equipment for other applications and future changes, or for qualification of devices mounted on the equipment (for example instrument mounted on panel). The location of the monitoring sensors shall be documented including photographs.

6.2.6 *Demonstration of operability*

According to the criteria of clause 4 during and/or after the seismic tests, the equipment shall perform its safety related function.

6.2.7 *Test sequence*

In general, seismic tests should be conducted according to the following sequence and as described in the relevant specification:

- a) Preliminary inspection in order to check the integrity of the equipment
- b) Functional check (prior to the test)
- c) Vibration response investigation (exploratory test)
- d) Seismic qualification test including functional check
- e) Functional check (after the test)
- f) Final check.

The sequence of seismic tests within the global qualification process is identified in IEC 780.

6.2.8 *Vibration response investigation*

The specimen should be subjected to a vibration response investigation to determine its dynamic characteristics and as an aid in the justification of the test method chosen or for the results of the test.

The vibration response investigation supplies data on the natural frequencies, and on the damping of the equipment, and is useful in the choice of single or multiaxis testing.

The test shall be in the form of single axis excitation at low input vibration levels (lower than the required dynamic qualification level). The test shall be performed (in each principal axis) in the frequency range equal to or greater than those specified for seismic input motion (see 6.2.2).

The exploratory test can be performed in different ways, by base excitation or by impedance methods.

6.2.8.1 *Exploratory test by fixing points excitation*

The most common method employed is a continuous sinusoidal sweep input at low level acceleration with the frequency sweep rate not greater than 2 octaves per minute (1 octave per minute is often used). The selected acceleration level should be such as to obtain a good signal to noise ratio for test facilities (normally, this value is chosen to be in a range between 0,1 g to 0,2 g).

Similar results can be obtained carrying out the resonance search by low level broad-band periodic random motion.

6.2.8.2 *Exploratory test by impedance method*

The resonance search can be carried out by exciting the structure with movable shakers or by impact testing. The signal coming from monitoring instruments (accelerometers, strain gages, etc.) shall be recorded and analyzed in order to obtain the responses curves of the equipment (i.e. acceleration versus frequency, or better the transfer function between responses and excitation). These curves show the resonant frequencies of the equipment.

For the test of 6.2.8.1 and for this test, it should be noted that:

- due to physical complexity or restricted access to critical parts, the exploratory tests may not detect all the critical frequencies;
- because of non-linearities, resonance responses at high levels may differ in frequency and damping from those recorded at lower levels and then some resonances may not be visible at low excitation. The result of a low-level exploratory test may, therefore, not always provide valid information regarding the specimen's dynamic response;
- when an exploratory test is selected in order to justify the chosen test qualification method of single frequency waves, it may be useful to carry out vibration response investigation at two different levels in order to indicate non-linearity.

Resonance search at two different levels may also be useful to justify qualification by a combination of analytical and test methods.

In any case, if the configuration of the equipment is such that frequencies cannot be ascertained with reliability, the testing method shall be one of those described in 6.5.2.

6.2.9 *Qualification test method*

6.2.9.1 *General*

As is well known, seismic excitation occurs simultaneously in all directions in a random way. According to this point of view, the test input motion should consist of three mutually independent waveforms applied simultaneously along the three orthogonal axes of the equipment.

However, taking into account that three axial testing installations are rare and that triaxial testing is desirable when significant coupling exists simultaneously between the two preferred horizontal axis of the specimens, biaxial testing with multifrequency independent input motion in the horizontal and vertical direction is an acceptable test. Tests shall be performed according to 6.3.2 and, in terms of total duration and fatigue induced, are intended to become conservative.

In some cases, single axis tests with multiple or single frequency excitation are also acceptable methods of test if properly justified considering the effect of coupling between axes.

6.2.9.2 *S1 earthquake and S2 earthquake testing*

Seismic testing specifications include the effect of one (or more) S1 and S2 earthquakes. Five S1 tests are usually considered to be sufficient in the absence of more accurate information.

The purpose of multiple S1 testing is to demonstrate that earthquakes which are most likely to occur, are not detrimental to functional safety of the specimen's performance and do not generate fatigue or ageing conditions whose undetected presence could lead to defective performance during a subsequent S2 earthquake.

When the required number of operational checks of the specimen is high, it may be necessary to simulate more S2 tests than specified to allow checking of the specimen part by part.

NOTE - In such cases, fatigue at low number of cycles may be revealed; the test acceptance criteria of 6.2.13 shall be modified in order to take into account the following aspect: repairing without repetition of the complete series of tests is allowed providing that the dynamic characteristics of the specimen do not change significantly.

Both the shape and magnitude of the spectrum may differ for the two seismic levels of S1 and S2. To qualify the specimen, it is therefore necessary to know the spectra corresponding to each of these seismic levels. It is commonly assumed that the S2 spectrum has the same shape as that for the S1 but twice as great.

For uniaxial or biaxial tests carried out according to 6.3.1 and 6.3.2, it is permissible to perform the required S1 in the first step followed by the S2 repeating the same sequence with the remaining arrangements of the specimen.

6.2.9.3 *Test response spectra (TRS) acceptability*

Normally, random vibration or synthesized input waveforms should be used in carrying out the test (see 6.5.2).

The actual input motion obtained starting from RRS shall have sufficient intensity and duration in such a way that its TRS envelops the RRS or the applicable portion of the RRS taking into account the dynamic characteristics of the equipment under test, i.e. the natural resonance frequency.

If resonance phenomena does not exist below 5 Hz, the RRS should be enveloped for frequency values above $5/\sqrt{2} = 3,5$ Hz.

In general, the TRS should envelop the RRS closely and should have a similar shape so that frequency characteristics of the input motion are consistent with the frequency content of the RRS.

If resonance phenomena exist below 5 Hz, it is accepted that the TRS stays below the RRS according to the limit of the vibration table provided that an alternative test is performed using equivalent excitation methods (such as concentrated excitation), and their equivalence is demonstrated.

In any case, the TRS shall envelop the RRS in correspondence with both the natural frequencies of the equipment under test and with high frequencies (ZPA). TRS shall be computed with 1/3 octave (or narrower) bandwidth resolution using justifiable analytical technical or response spectrum analysis equipment.

6.2.9.4 *Selection of damping*

In order to compare TRS with RRS, any representative value of damping may be employed, which should not necessarily correspond to the equipment damping. This damping value should be in principle equal for the two spectra. In some cases, however, when data from past qualification are used, two possibilities exist:

- a) the TRS has a damping level greater than the RRS; in such a case if the other requirements of clause 6 are satisfied the qualification is acceptable;
- b) the TRS has a damping level less than the RRS; in this case it is necessary to reanalyze the data prior to reaching a conclusion. One possibility is to analyze the test motion in order to produce a TRS with the same damping as the RRS.

If necessary, reference can be made to the damping level corresponding to the one measured on the specimen or to a value selected as given in 5.2.4.

6.2.9.5 *Fragility testing*

Fragility testing is used to qualify equipment by determining its ultimate capability; such information may be used to prove adequacy for a given requirement.

The methods of 6.5 can be used to establish fragility data and to assure proper application.

A measurement of the equipment fragility level for a particular motion constitutes a demonstration of its ultimate capability to perform that motion. For example, if the RRS is broad-band, the multifrequency fragility curve (TRS) at appropriate damping (6.2.9.4) should overlay the RRS and be demonstrated to be higher than the required spectrum.

6.2.9.6 *Proof testing*

Proof testing is used to qualify equipment for a particular application or requirement. Specimens shall be tested in accordance with 6.5.

6.2.10 *Assembly testing*

It is normal to test large complex assemblies by simulating the most critical in-service conditions. In such a case, the specimen is subjected to the required seismic input motion while the operating conditions are applied or simulated and while its performance is recorded during the tests.

This might, however, prove to be impracticable in the event of complex specimens, which may include many devices forming parts of several systems and being connected to other equipment situated at numerous positions within the structure (i.e. control panels containing items belonging to different circuits).

The following alternative is allowed:

- testing of the assembly with devices inoperative or simulated by an equivalent dummy load, and
- recording the response of devices at the point of installation in order to obtain response spectra that will be used in the qualification of the devices.

If there are many devices mounted on different locations of different panels, it is suggested that the required spectra be obtained as an envelope of the response spectra of the whole mounting location. (see 6.2.11).

The data so obtained can be compared with the data obtained from previous qualification or from fragility data of the devices in order to verify that the RRS of the devices is lower than the TRS required in the application (see 6.2.11).

In assembly testing, the method described in 6.5.2 or any other justifiable method may be used.

After testing, the assembly shall be inspected and the integrity of all the unmonitored devices, such as cabling, checked.

The purpose of installing inoperative devices is to ensure that the specimen possesses the same dynamic characteristics as in normal operation.

In order to take into account the interaction between the assembly under test and the interfaced equipment, additional consideration of the dynamic interaction between the equipment can be required (see clause 5). For example, the number of vertical sections of control or power panels that can be qualified by tests are of course limited. In this case, the dynamic interaction between interfaced equipment shall be considered.

This requirement shall be evaluated according to the type of equipment and shall be defined on a case-by-case basis. Functional performance of the assembly submitted to qualification tests shall be defined on a case-by-case basis.

6.2.11 *Devices testing*

Each device (relays, breakers, etc.) shall be subjected to testing while simulating its functional behavior.

Normally, the device is fixed to the vibration table in a manner that simulates the in-service conditions. The device shall be subjected to a seismic input motion enveloping the response expected on the mounting positions of the assembly items (see 6.2.10).

If not, the device should be installed on the vibration table in such a way as to ensure dynamic simulation of the required installation and then should be subjected to a seismic motion equal or greater than that required for the assembly.

Some types of assembly produce impact or rattling that generate high frequency responses at the mounting location of the devices, and testing of devices with input motion obtained from test on the assembly is recommended.

The upper frequency values for the tests may be higher than 35 Hz (up to 100 Hz). Otherwise, it is necessary to provide additional data in order to demonstrate that the test is conservative and possible effects of impact and rattling have been taken into account.

Testing of devices may require a frequency range higher than 35 Hz (up to 100 Hz).

6.2.12 *Testing method for a specimen without critical frequencies*

If it can be shown that the equipment is not resonant in the frequency range of the amplified zone of the response, it can be considered rigid and may be tested statically or according to the criteria of 6.5.3.

6.2.13 *Test acceptance criteria*

Inspection shall be made to check the integrity and performance of the equipment before, during and after the test (according to the type of equipment).

The acceptance criteria shall be specified in advance and the following minimum conditions shall not occur, as far as applicable:

- a) structural failure or deflection which would inhibit or prevent performance of any safety related function is not accepted;
- b) loss of output signal; for example open or short circuit;
- c) spurious or unwanted output; for example relay contact bounce exceeding the specified limits;

- d) drift of set-point or trip setting greater than the specified accuracy over the full range;
- e) calibration shift greater than the specified accuracy over the full range; this parameter need not be determined during vibratory excitation;
- f) structural failure; for example broken or loosened parts or deformation resulting in loss of function;
- g) loss of required performance characteristics; for example inability to change state;
- h) loss of pressure boundary integrity; for example leakage;
- i) correct functioning may be required during and after the test or merely after the event.

Sufficient instrumentation shall be provided to monitor and record device performance during vibratory excitation; i.e. in order to show that each of the above criteria have been satisfied.

Whenever these criteria are not met, the specific deviation data shall be evaluated according to the relevant specification for specific applications.

Equipment assemblies or devices which fail to give satisfactory test results shall be repaired, modified, or replaced but in any case the entire test of the equipment shall be repeated and satisfactory results obtained. If devices are replaced during a test, they shall be replaced according to the general criteria of IEC 780, aged if necessary.

6.3 *Single and multiaxis testing*

6.3.1 *Single axis testing*

Single axis testing applied successively in the three preferred axes of the equipment can be justified in the following circumstances:

- when there is little or no coupling between the three preferred axes of the equipment taken in pairs;
- when the equipment is subjected only to single axis excitation due to its installation conditions;
- when the multidirectional excitation is taken into account by an appropriate scaling factor. For example, if an element is normally installed on a specimen which amplifies motion in a single direction, or if the construction and/or mounting of a component restricts its motion to one direction, a single axis test may suffice.

However, if testing in all three axes is not carried out, this shall be justified. Testing shall be performed according to the criteria of 6.5.

6.3.2 *Biaxial testing*

Biaxial tests are normally intended as the application of input motion in the horizontal and vertical direction. According to the type of testing installation available, two cases may be encountered.

6.3.2.1 *Biaxial installation*

Using multifrequency waves (see 6.4a)), tests shall be carried out by applying independent simultaneous excitation signals along the horizontal and the vertical axes of the specimen and repeated after a rotation of 90° of the specimen about the vertical axis. The TRS obtained along each axis shall envelop the RRS according to the criteria of 6.2.9.3.

6.3.2.2 *Single axis installation*

If a biaxial installation is not available, a vibration table moving along an inclined plane with respect to the horizontal axis is acceptable, the installation plane remaining horizontal.

Since in this case the motion along the two directions is not independent, four tests are then performed in order to test in and out of phase. The specimen shall be installed on the vibration table in the positions indicated below:

- Position 1: specimen in position with one of the chosen horizontal axes along the direction of excitation
- Position 2: specimen rotated through 180° about the vertical axis from position 1
- Position 3: specimen rotated through 90° about the vertical axis with respect to position 1
- Position 4: specimen rotated through 180° about the vertical axis with respect to position 3.

With this type of test, the spectra obtained have the same shape for all three axes of the specimen but with relative horizontal to vertical levels determined by the slope of the vibration table.

Normally this type of table has a slope of 45° but in some cases may have a different slope in the range 25° to 45° .

The TRS projected along each one of the two axes of the test specimen shall envelop the RRS of the corresponding axis according to the criteria of 6.2.9.3. This test may be conservative since the excitation peaks are occurring simultaneously along both axes.

6.3.3 *Triaxial testing*

The test is performed with simultaneous input waveforms along two orthogonal horizontal axes and vertical axis of the specimen, each producing a TRS that envelops the corresponding RRS along that axis according to 6.2.9.3. Two cases may be encountered according to the type of installation available.

6.3.3.1 *Triaxial installation*

The test is performed with simultaneous but independent input waveform into the three preferred axes of the specimen.

6.3.3.2 *Biaxial installation (vertical - horizontal)*

As triaxial installations are rare, at present the use of a biaxial vibration table with independent simultaneous excitation signals in the horizontal and vertical plane is suggested.

- The specimen should be mounted and tested on the vibration table with the preferred horizontal axis parallel to the excitation.
- Then, the equipment is rotated by 90° around the vertical axis and tested again.
- The specimen should then be mounted on the vibration table with one of the chosen horizontal axis at 45° with respect to the excitation axes and tested.
- Then, the equipment is rotated 90° around the vertical axis and tested again.

The excitation level in the horizontal plane shall be adjusted in order to obtain a TRS that envelops the RRS along the two chosen orthogonal horizontal axes of the specimen (see 6.2.9.3).

If independent random inputs are not used, and a single axis installation such as described in 6.3.3.2 is available, four tests should be run. The specimen is mounted on the vibration table as described above according to the excitation axis and tested. The specimen is rotated into four different positions as discussed in 6.3.2.2.

6.4 *Test wave selection*

The selection shall take into account the anticipated characteristics of the specimen in its installed position and under the influence of the specified earthquake. Whichever waveform is adopted, the test response spectrum shall envelop the RRS or its significant portion thereof.

The test waves can be divided into two categories:

a) Multifrequency waves:

- Random vibration
- Time history (synthesized or not).

b) Single frequency waves:

- Sine dwell
- Sine beat
- Sine sweep
- Other waveforms (requiring justification).

6.5 *Testing waveforms*

6.5.1 *General*

Whichever test waveform is used, it shall:

- produce a TRS that envelops the RRS over the test frequency range - TRS and RRS shall be compared to the same damping value or with a damping value of TRS greater than that of the RRS;
- possess a peak acceleration value equal or greater than the ZPA of the RRS;
- ideally not include any frequency greater than the maximum specified by the RRS.

6.5.2 Multifrequency testing

Multifrequency testing waves shall be in accordance with the rules indicated in 6.5.1 and 6.2.9.3. In order to develop a multifrequency waveform, different techniques may be used according to the test control system available (digital or analog).

6.5.2.1 Random signal test

The random signal test is performed by applying a random wave to the specimen adjusted to the frequency range defined by the RRS at a level such that the TRS envelops the RRS according to 5.2.9.3. If the method is used with an analog system, the level is adjusted to 1/3 octave bands with the bandwidth of each band defined according to the equipment available.

If a digital system is used, the signal is adjusted at intervals of 1/3 octave (or narrower)¹. In this way, it is possible to develop a suitable TRS without using an excessive maximum acceleration level as in the case of an RRS having low ZPA and high amplification. The signal is the result of the combination of narrow band components superimposed on a broad-band motion at the necessary level. Other possibilities for obtaining a TRS that envelops the RRS closely are described in 6.5.2.1 and 6.5.2.2.

6.5.2.2 Random signal with superimposed single frequency signals

When the RRS shows low level ZPA and high amplification, it is acceptable to adjust the random input at a level not substantially greater than that required to meet the ZPA and then superimpose single frequency signals such as sine-dwell or sine beat to meet the response spectra according to 6.2.9.3.

The bandwidth of the spectrum may require sine-dwell or sine beats at more than one frequency. They shall start simultaneously and their duration shall be equal to the test duration (sine beats shall be spaced). The number of cycles per beat may be adjusted in order to meet the requirements.

If the bandwidth of the RRS has been artificially broadened, a series of tests having different single frequency sine dwell or sine beats superimposed on the basic random motion are allowed provided that complete justification is given.

6.5.2.3 Time history test

The test is performed by applying a previously synthesized time-history to the specimen (see figure 4) to simulate the specimen's probable excitation. The waves can be obtained by a combination (summation) of individual narrow band components superimposed on lower level broad-band random motion.

This approach is suitable for a digitally controlled system which is allowed to obtain a table motion whose TRS envelops the RRS according to the criteria of 6.2.9.3 without introducing an excessive ZPA level.

Different techniques can be used according to the computer program available. The first one is readily used in a computer-controlled installation.

¹ The suggested values are 1/3 octave for 10 % or greater damping, 1/6 octave for damping between 2 % and 10 % and 1/12 octave for damping of 2 % or less.

- Combination of multiple sinewaves

The signal consists of a summation of multiple sinewaves at distinct frequencies controlled in amplitude and randomly phased in order to meet the requirements of 5.2.9.3. All sinewaves shall start simultaneously and continue for the duration of the test. The frequencies are spaced at 1/3 octave (or closer).

When the method is used in order to meet broad-band response spectra, the results are very similar to broad-band random motion.

- Combination of sine beats

The method is similar to the above, but uses a combination of sine beats continuously repeated for the duration of the test.

- Combination of decaying sine waves

The multifrequency wave is obtained as an aggregate of decaying sine waves starting simultaneously and continuously present for the duration of the test. In this case, the undamped frequencies of the component waves are also spaced 1/3 octave apart (or closer).

6.5.3 *Single frequency testing*

The single frequency wave shall produce a motion such that TRS, at the test frequency, is larger or equal to the RRS. The peak acceleration shall be at least equal to the ZPA of RRS except at low frequencies for which only the RRS value should be met (see 5.2.9.3).

Taking into account that the RRS is usually broadened in the amplified region, it is acceptable to carry out the test at the center frequency of the broadened region and at frequencies spaced 1/3 octave interval apart (or closer) until the amplified area of the spectra is covered (see figure 1). This guards against the possibility that some critical frequencies are undetected during the investigation response test. Specimens having a critical frequency shall be tested at that frequency and at two adjacent frequencies for which the TRS of the test wave (at critical frequency) is reduced by a factor of $\sqrt{2}/2$ (see figure 1). In this case, it is suggested that the resonance search is repeated to verify that the critical frequency remains in the interval defined by the adjacent frequency.

The tests may consist of the application of a train of at least five sine beats or sine dwell (see figures 2 and 3) at each frequency with a pause between any sine beat or sine dwell, in order to have no significant superposition of equipment response.

Each sine beat (or sine dwell) should have a sufficient intensity and number of cycles (usually 5 to 10) to produce a TRS according to the above criteria. For a given peak amplitude of the sine beat or sine dwell the conservatism of the test increases as the number of cycles increases (see figure 11).

6.5.4 *Other waveforms*

Other waveforms can be used if justified in accordance with the requirements of 6.5.1. If decaying sine waves are used, the same criteria applies; the peak acceleration of decaying sine waves shall correspond to the ZPA value of the response spectra.

In any case, the single signal (not the train) shall give a TRS that envelops the RRS at testing frequency and at ZPA. Sine sweep tests at a sweep rate not greater than 2 octaves per minute may also be used in the frequency range of interest. The sweep rate should be chosen according to the damping value of the equipment. The TRS shall be evaluated around any single frequency.

7 Documentation

Documentation to substantiate qualification should include:

7.1 General

- Details of the equipment (4.2.1)
- Details of the seismic specification (4.2.2)
- Details of the test criteria (4.2.3)
- Documentation which identifies the equipment production route and the inspection which applies to it.

7.2 Qualification by analysis

Details of the analysis should be presented in a step-by-step form which is readily auditable by persons skilled in such analysis and should include a listing of the potential failure modes considered in the analysis where computer codes are used. A reference to a validation document shall be provided.

If proof of performance is obtained by extrapolation from similar equipment, the data shall contain:

- description of both equipment;
- test data on original equipment;
- a detailed description of the differences between the two equipment;
- justification that the differences do not degrade the seismic performance below acceptable limits (may require some additional analysis or testing) including any additional supporting data.

7.3 Qualification by test

- Test facility:
 - . Location
 - . Test equipment and calibration
- Test methods and procedures
- Test data (including proof of performance)
- Results and conclusions (particularly natural frequencies and maximum accelerations such as comparison of TRS and RRS)
- Production inspection data for the equipment which was tested
- Ageing: Information on ageing procedures.

7.4 Continuity

The documentation shall enable the qualification to be extended to the series production of the equipment.

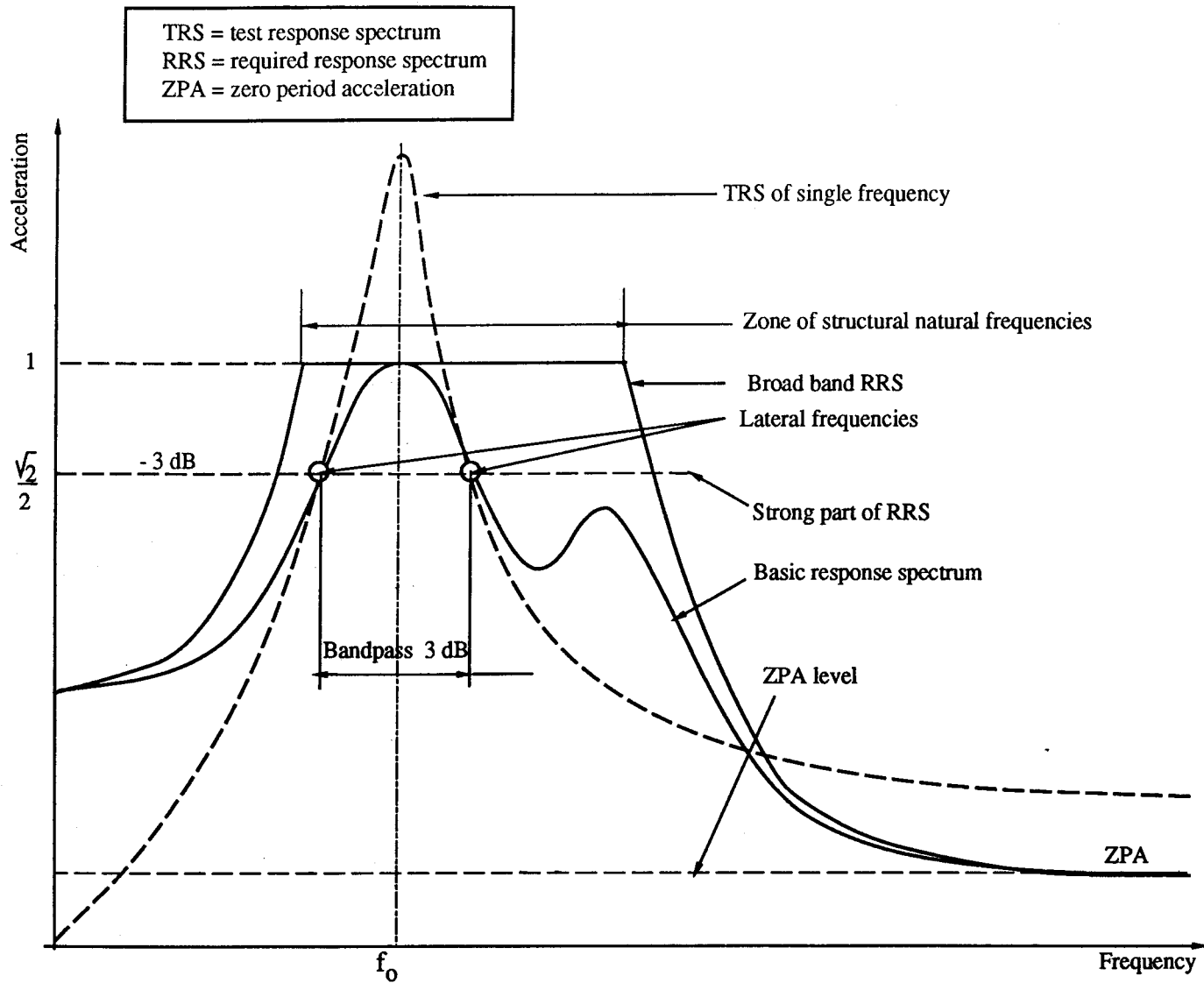


Figure 1 - Typical envelope response curve

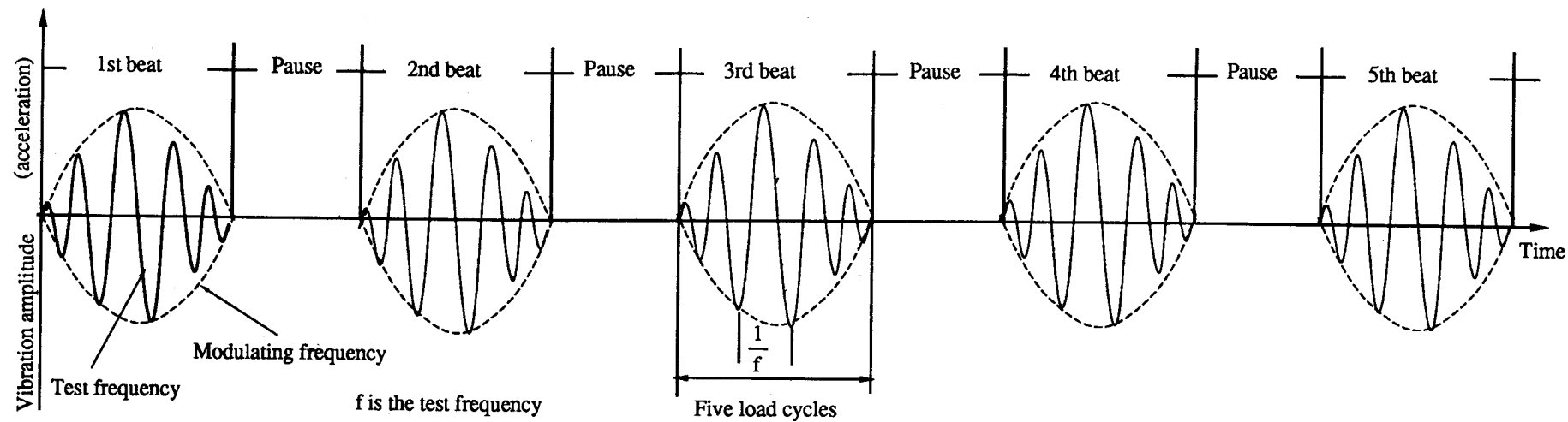


Figure 2 - Train of five beats with five load cycles

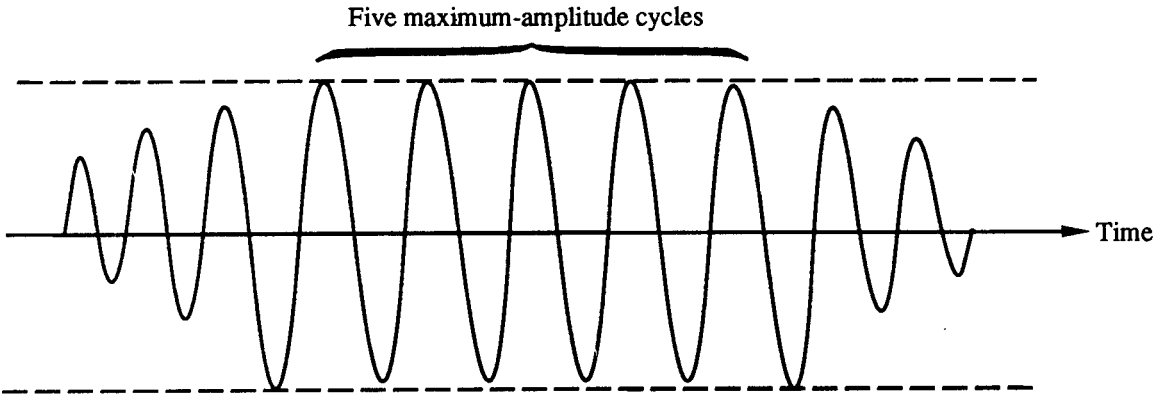


Figure 3 - Sine dwell

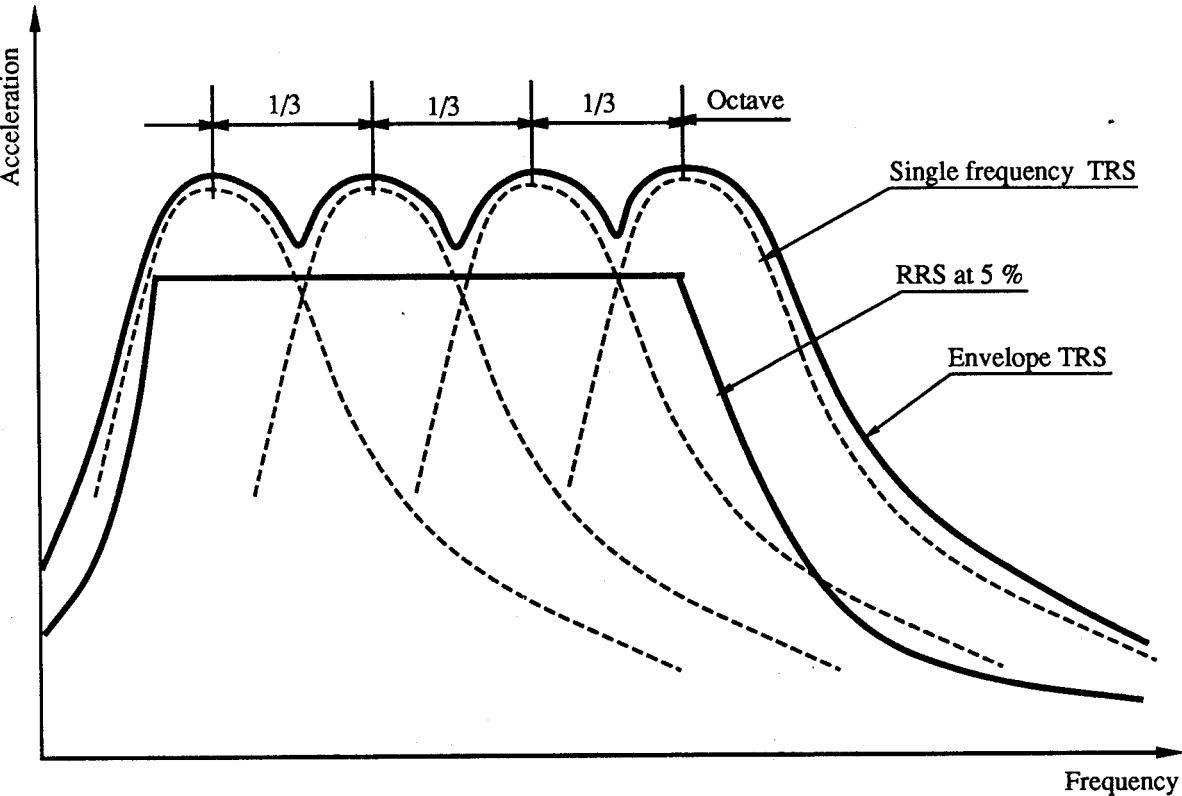


Figure 4 - Types of response spectrum envelopes

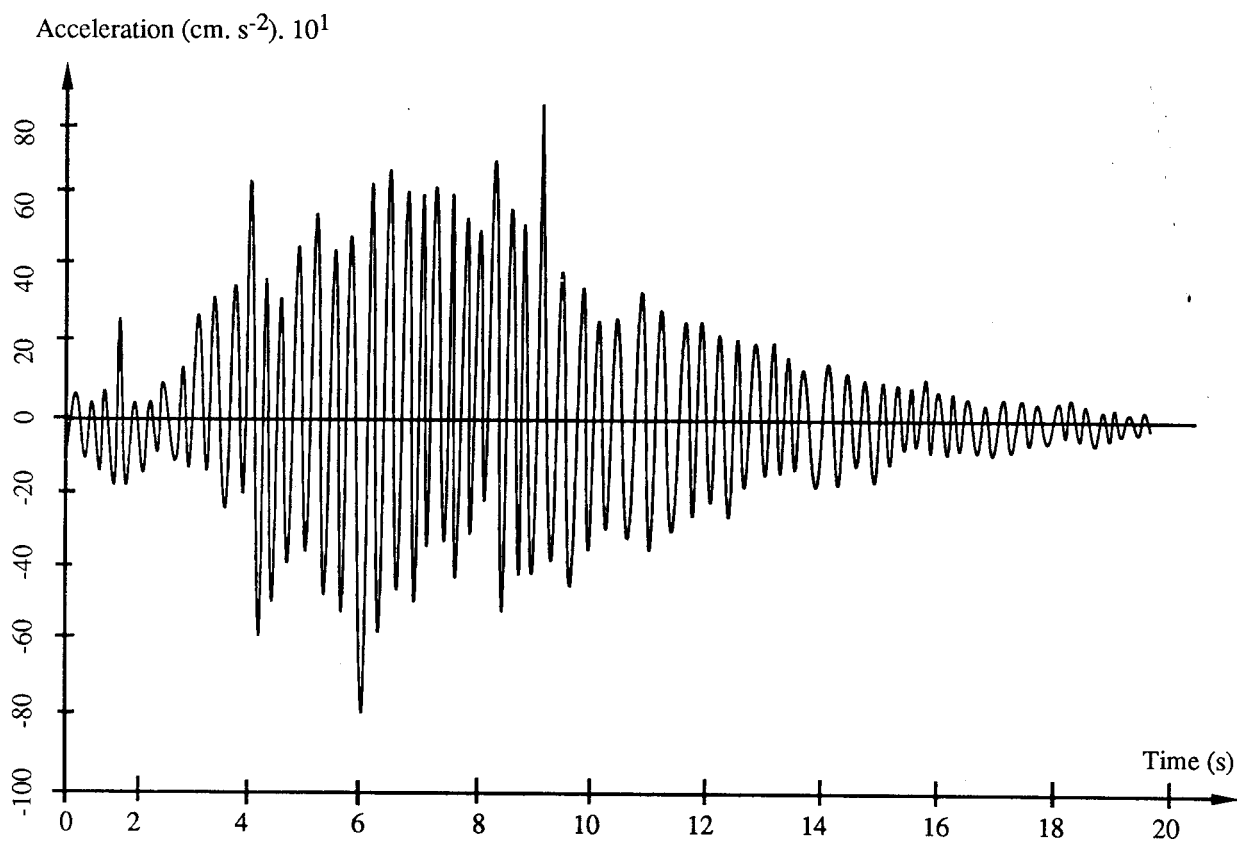


Figure 5 - Time history

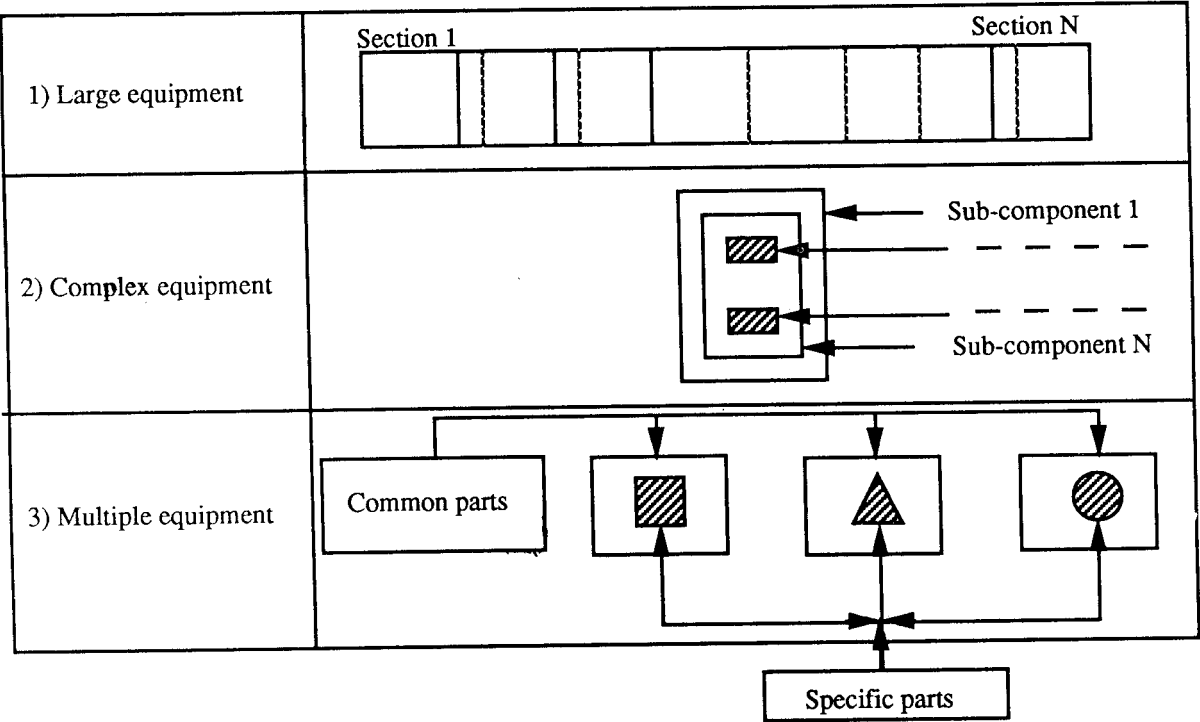


Figure 6 - Schematic procedures to dissociate large, complex or multiple equipment into several sub-assemblies

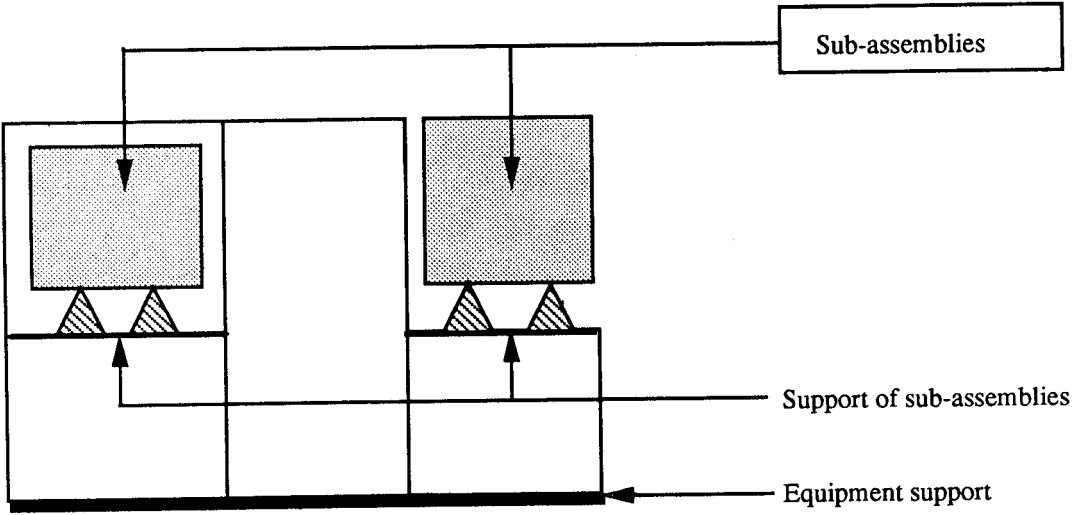


Figure 7 - Seismic loading of sub-assemblies

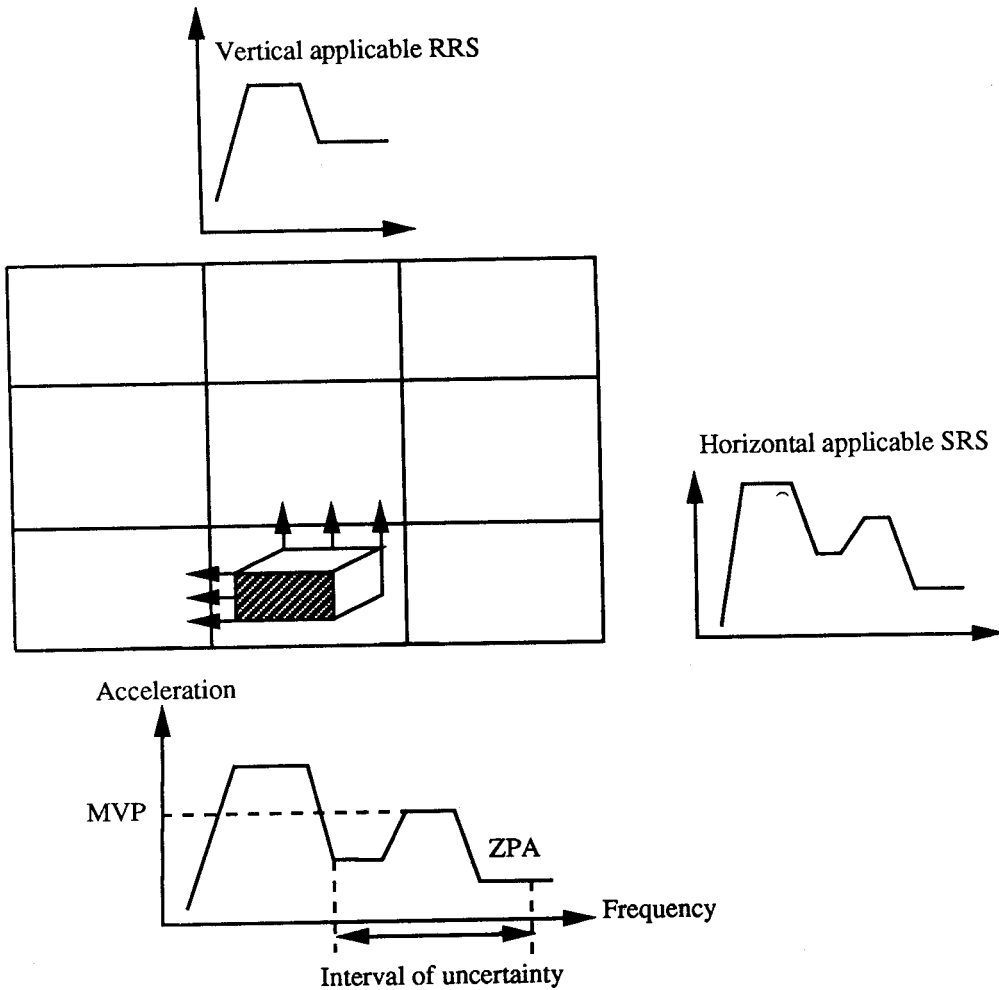
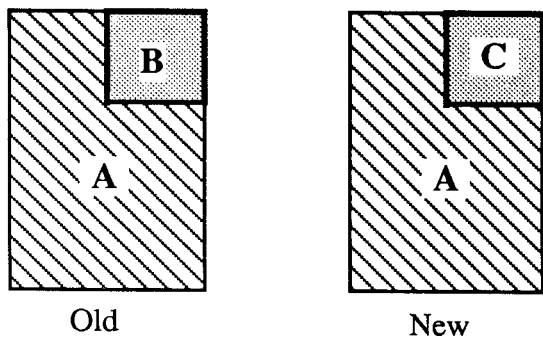


Figure 8 - Applications of horizontal and vertical RRS acceleration



1) Sub-assembly A

Verification and, if necessary, additional actions to ensure that the available qualification covers the boundary conditions and coupling effects of:

- removal of B
- mounting of C

2) Sub-assembly C

Qualification of C to the conditions resulting from the mounting in A.

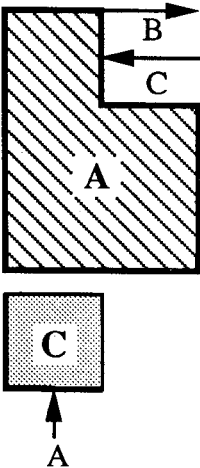
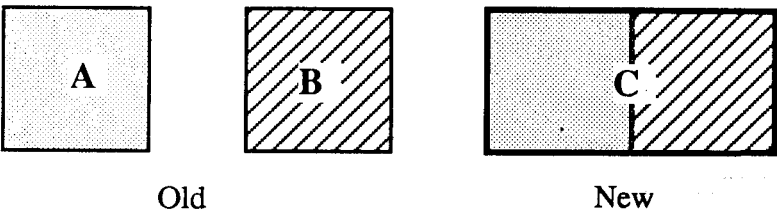


Figure 9 - Equipment resulting from the modification of sub-assemblies



Verification and, if necessary, additional actions to ensure that available qualification of the constituents A and B covers the boundary conditions and coupling effects resulting from their assembly.

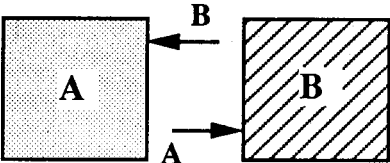


Figure 10 - Equipment resulting from the assembly of two or more sub-assemblies

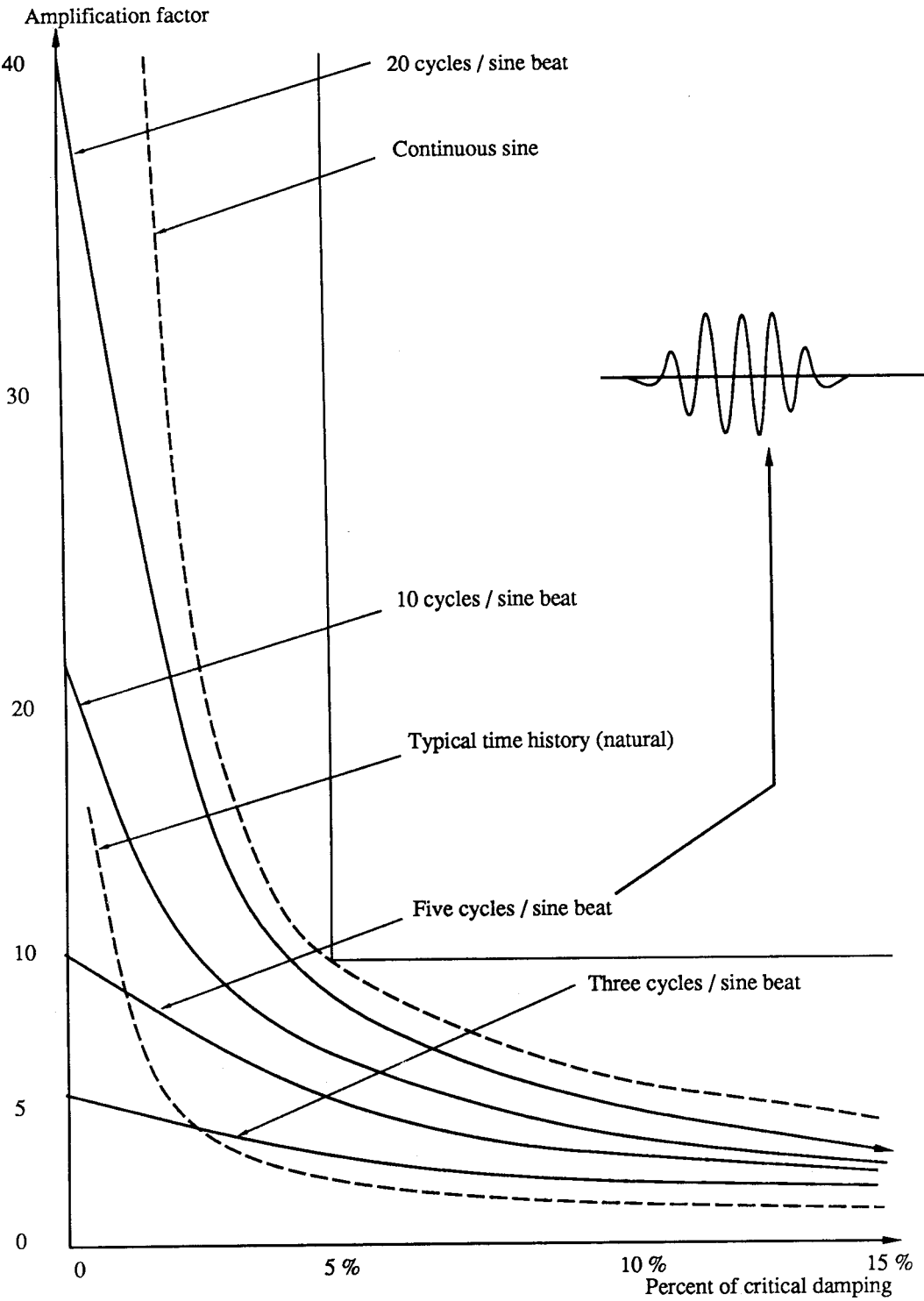


Figure 11 - Wave amplification factors

ANNEX A

QUALIFICATION BY EXPERIENCE

A.1 Introduction

There are many types of equipment which are similar in function and physical characteristics to equipment that has been previously qualified by testing, analysis, or a combination of both testing and analysis.

In addition, other equipment types are similar to equipment that has been in service for various periods of time and has been exposed to inplant vibration and natural seismic disturbances.

Therefore, qualification of these equipment types may be achieved by justifying their similarity with previously qualified equipment or with equipment that has been exposed to other more severe environments. Similarity of the excitation environment and of the equipment characteristics shall be established by techniques that can be technically justified. Due consideration to changes in design and manufacturing techniques shall be considered as part of the technical justification supporting similarity.

A.2 Experience data

Experience data may be derived from a variety of sources.

It may be:

- a) analysis or test data from previous qualification programs;
- b) documented data from equipment in facilities which have experienced natural earthquakes;
- c) data from operating dynamic loading or other dynamic environments.

Depending on the source and level of documentation detail available, various approaches are appropriate. The following sub-clauses provide additional detail specific to each case.

A.2.1 *Previous qualification*

Many seismic and dynamic qualification programs have been conducted for various safety equipment items by the nuclear industry and can be used to develop an experience data base. Some of these equipment items may have been qualified by incorporating a full test program along with preliminary exploratory (resonance search) tests. Others have been qualified using analytical techniques as described in clause 5 or by using a combined test and analytical technique. In order to use this experience data base, the input motions for which the equipment was previously qualified shall have been clearly documented, together with pertinent qualification parameters, such as resonant frequencies, damping and response throughout the equipment.

A.2.2 *Earthquakes*

Another type of experience data consists of the documented performance of equipment in facilities that have been subjected to an earthquake. The data base equipment can be identical or similar (construction, dynamic response, etc.) to the equipment being qualified.

It is preferable that the earthquake be qualified by recorded measurement of the earthquake induced motion at, or near, the equipment mounting location. However, it is recognized that this is not generally available; therefore, alternatively a documented conservative estimate of input motion may be generated by extrapolation or interpolation of measurements elsewhere (see 6.3.1).

A.2.3 *Other experience*

The approach described above for natural earthquake data may also be applied to the use of operating dynamic loading or other documented dynamic environments as a basis for qualification. In any case, the principle of similarity shall be used to justify the approach.

A.3 **Similarity**

Qualification by the use of extrapolation from experience data shall be based on the concept of dynamic similarity. This concept recognizes that the qualification process for equipment is comprised of the following basic factors:

- a) excitation,
- b) physical system (dynamic properties and operability),
- c) dynamic response.

Generally, establishment of the dynamic similarity for the excitation and physical system will allow a successful qualification to be established by extrapolation from experience data. For example, assume that a given equipment item has been qualified to a specified excitation. Then, a second equipment item, whose physical system similarity can be established, is also qualified to the same excitation. Another example would be where two or more identical, or at least dynamically similar, items have each been qualified to different excitations. They can both have been qualified for another composite excitation, which can be shown to be similar to the original different excitations.

A.3.1 *Excitation*

Similarity of excitation constitutes likeness of parameters such as spectral characteristics, duration, direction of excitation axes, and location of measurement for the motions relative to the equipment mounting. Ideally, the experience response spectra (ERS) should be as alike as is practical for different excitations whose similarity is to be established.

However, a conservative composite excitation can be generated by extrapolations or interpolations of data whose parameters are not identical but are justifiable. For example, estimates may be based on measurements elsewhere on the structure or on other structures in the vicinity of the given equipment, if the estimates can be justified by calculations based on sound engineering methods using geophysical models, structural models, or both as applicable.

Likewise, excitations whose spectral content is significantly different may be used to generate lower level composite estimates providing that approximations for multimode response or cross axis coupling or both are accounted for. Justification for such approximations shall consider the absence of modal excitation caused by mismatch of spectral content in the composite RRS. Thus, the interaction of excitation characteristics and dynamic properties for the specimen shall be given consideration.

Duration of a composite excitation shall be similar to that from which it is derived. Furthermore, to provide for proper vibration buildup and low cycle fatigue effects, as with qualification by testing, any constituent experience data shall be based on a minimum of 15 s of strong motion duration or a justifiable equivalent.

The qualification shall account for the ageing effects of exposure to the required normal and abnormal conditions such as normal plant vibrations and the required S1. If no S1 can be documented in the data derived from experience, then the lack of fatigue effects shall be justified or a fatigue analysis shall be performed.

A.3.2 *Physical systems*

Equipment similarity shall be established for an equipment assembly, or a device or sub-assembly (including mounting), depending on the configuration of the new equipment to be qualified. For a complete assembly, similarity may be demonstrated through comparison of make, model and serial numbers and consideration of dynamic properties and construction.

Since the final objective of qualification by the similarity method includes consideration of the expected dynamic response, a rational approach can be made to establish similarity of dynamic structural properties by an investigation of physical parameters of equipment systems. This can be done by comparing the predominant resonant frequencies and mode shapes. These dynamic characteristics are dependent on parameters such as:

- a) equipment physical dimensions;
- b) equipment weight, its distribution and center of gravity;
- c) equipment structural load transferring characteristics and stiffness to resist seismic excitation;
- d) equipment base anchorage strength and stiffness to assure both structural integrity and adequate boundary conditions; and
- e) equipment interfaces with adjacent items or connecting accessories such as cables and conduits.

The relative difference, or dissimilarity, of all the above physical parameters makes it necessary to ensure that adequate similarity exists between equipment assemblies. In addition, it should be ensured that changes from the original data base equipment do not result in the formation of previously nonexistent resonances and do not introduce new mechanisms for malfunction.

For the equipment where seismic qualification can be proved by showing that individual safety devices are performing properly during the earthquake, a device or subassembly similarity evaluation approach may be considered. The similarity of physical systems will be applied for the individual devices. In this case, the similarity in mechanical device and electrical operating principles shall first be addressed.

The physical system parameters, as applicable to equipment assemblies discussed above, may not be obvious, or may be difficult to define such as in an analysis or engineering judgement justification. Therefore the justification of similarities relies on the careful examination of the dynamic properties, anchorage, and the mechanical and electrical operating principles as applicable to the device. In any case, an appropriate physical parameter data base shall be used to demonstrate that similar equipment behavior will result between the data base equipment and the equipment under investigation. For complex devices, a test will be required to show proper justification.

A.3.3 *Dynamic response*

A physical system response can be described using the same quantities as an excitation (i.e. duration, frequency content, amplitude, etc.), or using a physical system description giving failure modes, failure criteria and criteria for acceptance or rejection.

When the physical system characteristics are known through the experience data (by any one of the previously mentioned methods of 5.2.1 through 5.2.3) and the excitation characteristics are also available, then the system response can be evaluated and extended towards similar systems.

On the other hand, there are occasions where only response and physical system characteristics are available. For these situations, the excitation requirement can be evaluated in the light of the known response quantities and the physical system characteristics (obtained by methods 5.2.1 through 5.2.3). Such information for the input excitation may then be used to qualify similar equipment.

A.3.4 *Operability*

Equipment being qualified shall be capable of performing its safety function during and after an earthquake. The safety function during the earthquake may, or may not, be the same as after the earthquake. Therefore, for each qualification, the safety function shall be defined for conditions both during and after the earthquake. The experience data shall provide the documented evidence to support the demonstration of proper operability, as defined for each application. Where an active function, or the absence of a spurious function, is required during the earthquake, the experience data shall provide sound evidence that the equipment performed as required in a similar electrical system.

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